

THE IMPACT OF INVASIVE EXOTIC GRASSES ON QUAIL IN THE SOUTHWESTERN UNITED STATES

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ABSTRACT

Five native quail species inhabit arid and semi-arid ecosystems in the southwestern United States. One species is endangered, one species is declining throughout its historic range, another species is declining in portions of its historic range, and the other two species may be beginning to decline in selected portions of their respective ranges. A number of factors have been implicated for these declines, though habitat loss is frequently cited as the most common factor associated with southwestern quail declines. Exotic species invasions in the United States represent a significant economic and biological threat to the United States. Many exotic organisms introduced to the United States are threatening entire ecosystems, replacing native species and even threatening other native species with extinction. Numerous exotic grasses are invading arid and semi-arid ecosystems in the Southwest. Most exotic grasses were intentionally introduced for erosion control and to provide forage for livestock. Cattlemen sometimes favor exotic grasses in spite of their impacts to native biodiversity. The impacts of exotic grasses on vegetative communities are discussed, as well as their potential impacts on the five native quail species that inhabit the southwestern United States. Exotic grass eradication and control are also discussed, as well as introducing exotic grass pest management into existing land management programs. Research designed to determine the impacts of exotic grass invasions on quail and their habitat is recommended.

Citation: Kuvlesky, W. P., Jr., T. E. Fulbright, R. Engel-Wilson. 2002. The impact of invasive exotic grasses on quail in the southwestern United States. Pages 118–128 in S. J. DeMaso, W. P. Kuvlesky, Jr., F. Hernández, and M. E. Berger, eds. Quail V: The Fifth National Quail Symposium. Texas Parks and Wildlife Department, Austin, TX.

Key words: *Callipepla gambelii*, *C. squamata*, *Colinus virginianus*, *C. v. ridgwayi*, *Cyrtonyx montezumae*, eradication, exotic grass, forb, Gambel's quail habitat, insect, management, Masked bobwhite, Montezuma quail, native vegetation, northern bobwhite, research, scaled quail, southwest

INTRODUCTION

Quail are an important component of ecosystems they inhabit throughout southwestern North America. Recently, quail were one of the most abundant terrestrial nonmigratory bird species that inhabited arid and semi-arid ecosystems in this area. Five species of quail are native to southwestern North America, and one species has been introduced. The northern bobwhite (*Colinus virginianus*) has the widest geographic distribution, because it occurs throughout most of Texas and northern Mexico, however it is absent in the arid regions of west Texas and the western Panhandle of the state (Lehmann 1984:7). Masked bobwhites (*C. virginianus ridgwayi*), an endangered subspecies of the northern bobwhite, inhabit a restricted range in southeastern Arizona and northwestern Sonora, Mexico (United States Fish & Wildlife Service 1995). Scaled quail (*Callipepla squamata*) occur in semi-arid to arid regions of south and west Texas, northern Mexico, and throughout arid and semi-arid regions of New Mexico and southeastern Arizona (Brown 1989). Gambel's

quail (*C. gambelii*) occur in portions of West Texas and New Mexico and throughout most of the arid and semi-arid regions of Arizona (Brown 1989). Montezuma quail (*Cyrtornyx montezumae*) inhabit select grassland and oak savanna habitats in west Texas, northern Mexico, southwestern New Mexico and southeastern Arizona (Brown 1989). California quail (*C. californicus*), the only species not native to the southwestern United States, were introduced to a small area in eastern Arizona (Brown 1989).

Quail were fairly common residents of a variety of arid and semi-arid habitats in southwestern North America and occupied an important functional niche wherever they were found. Because quail are capable of responding very rapidly to an improvement in habitat conditions by producing large numbers of young, they can become very abundant locally in a short period of time (Stoddard 1931:102, Rosene 1969:65). Quail are an important prey species to many mammalian and avian predators (Lehmann 1984:265, Hurst et al. 1996). Today, quail are not only of ecological importance to the ecosystems they inhabit. They are

also of aesthetic and economic value to humans. Indeed, hunting is an important tradition in many southeastern states that has existed for more than a century (Stoddard 1931:435). Many southern plantations exist today solely for the purpose of maintaining a viable quail population that is hunted in the traditional southern manner which includes the use of mule-drawn wagons, gaited horses, and well-trained bird dogs. Quail hunting is also of economic importance in portions of Texas (Lehmann 1984, Guthery 1986) and Oklahoma, and to a lesser extent, in Arizona and New Mexico (Brown 1989). Hunters funnel millions of dollars annually into numerous rural southwestern communities for hunting leases, guided hunts, lodging, food, and ammunition. Healthy quail populations, particularly bobwhites, therefore offer a financial boon to tens of thousands of people.

Because quail are so important to the livelihood of so many people, and they are of aesthetic importance to both consumptive and nonconsumptive users, the current continental decline of quail populations (Brennan 1991, Church et al. 1993) has aroused considerable alarm among quail biologists, hunters, bird-watchers and people in local communities where quail are an important stimulus to business. Recent quail declines have been attributed to numerous phenomena. Loss of habitat has been cited frequently as one of the primary reasons quail populations have declined (Brennan 1991, Church et al. 1993) and rangeland and forest degradation has largely been responsible for the declines of western quail populations (Brown 1989, Kuvlesky et al. 2000, Engel-Wilson and Kuvlesky *this volume*). In addition to habitat destruction, Guthery et al (2000) suggested that slight temperature increases due to global warming could be rendering some portions of current bobwhite ranges uninhabitable because maximum summer temperatures now exceed the physiological thermal limits of bobwhites. Increased rates of mesomammalian predation has also been suggested as stimulating quail declines, particularly in the Southeast (Hurst et al. 1996). Unfortunately, one factor alone is almost certainly not the reason for the continued decline of quail populations in North America. Instead, Hurst et al. (1996) suggest that declining quail and wild turkey (*Meleagris gallopavo*) populations in the southeast are probably the result of a combination of factors, such as the interaction of habitat losses and increased vulnerability to predators, operating within and across landscapes on a regional scale of resolution.

Another perspective has been offered by Guthery (1997) when he argued that the recent decline of quail populations is in reality a spatial/temporal issue. He claims that given sufficient useable space, quail populations should be able to maintain themselves at self-sustainable levels. Loss of habitat, increasing temperatures, and increased predator populations simply represent factors that decrease useable space for quail populations. If Guthery's assessment of quail declines is accurate, then anything that reduces useable space-time represents a threat to quail populations. It is conceivable that exotic grass infestations and lack of bare ground due to the prevalence of sod-forming grasses

impact usable space during at least portions of the quail year. Usable space could be reduced during early summer if insect abundance is low in exotic grass pastures because insects comprise a substantial portion of the diets of nesting hens and young broods during April–July. Conversely, exotic grass plantations may increase useable space in regions where grass cover is limited if these areas provide correct habitat structure. Abundant speculation exists regarding the exotic grass/quail issue because few scientific facts are currently known. We postulate that exotic grasses render space unusable by quail. The conversion of millions of hectares of native rangeland in Texas, New Mexico, Arizona and northern Mexico to exotic grass plantations is a serious threat that has been largely ignored. The primary objectives of this paper are to first review the current state of our knowledge regarding the impacts of exotic grass invasions on quail populations in the southwestern United States, and then provide suggestions for future research projects regarding the exotic grass/quail issue.

EXOTIC GRASSES IN THE SOUTHWEST

Exotic flora and fauna have become a major threat to the natural resources of the United States over the past 50 years. Exotic species, also known as invasive, alien, foreign, introduced, nonnative and/or nonindigenous species, are plants and animals that have been introduced into an environment in which they have not evolved and usually have no enemies to limit their reproduction and expansion into new habitats (Westbrooks 1998). Pimm and Gilpin (1989) and Randall (1996) recently ranked exotic species invasions, behind habitat loss as the second greatest threat to endangered species in the United States. However, exotic plant invasions often represent habitat loss so the invasion of exotic species may be an even greater threat than previously realized (Wilcove et al. 1998). Between one half (Wilcove et al. 1998) and two thirds (Westbrooks 1998) of the endangered species in North America and Hawaii are threatened by exotic species.

Introduced plants alone threaten many ecosystems throughout North America. Like most of the United States, exotic plants have also become naturalized in the southwestern United States and have, to varying degrees, simplified native vegetative communities throughout this region. A number of exotic grass species were introduced to the southwestern United States by livestock producers and federal and state agricultural agencies, to curb erosion and provide forage for livestock (Bahre 1991, Roundy and Biedenbender 1996). Buffelgrass (*Cenchrus ciliaris*), Kleberg bluestem (*Dicanthium annulatum*), King Ranch bluestem (*Bothriochloa ischaemum*), Lehmann lovegrass (*Eragrostis lehmanniana*), and Boers lovegrass (*E. curvula* var. *conferta*) represent some of the more common exotic African grass species introduced to the southwest. The majority of these grasses have naturalized and have been enormously successful in expanding their ranges. Typically exotic grasses become established on

disturbed sites such as highway right-of-ways, oil and gas pipelines, and drilling sites, and then aggressively invade additional areas by modifying the environment in a manner that favors their establishment. For instance, buffelgrass, Lehmann lovegrass and cheatgrass (*Bromus tectorum*), modify natural fire cycles by increasing the periodicity of fires which creates better growing conditions for plant, and in this manner exotic grasses invade more acreage. Consequently, exotic grass invasions in the Southwest are likely occurring at a rate far more rapid than people realize and most ecologists have no idea what impact this invasion is having on the native flora and fauna. Nevertheless, the few studies that have been conducted elsewhere indicate that invasive exotic plants negatively impact native wildlife populations.

IMPACTS OF EXOTIC GRASSES ON PLANT COMMUNITIES

Many exotic plants form dense monocultures that reduce species diversity, and inhibit survival and re-establishment of native species (D'Antonio et al. 1998, Christian and Wilson 1999, Brown and Rice 2000), many of which may be important plants for insects and for producing seeds eaten by quail. Many exotic plant species are highly competitive and are able to out compete natives for nutrients, water, and light. Allelopathy is another mechanism by which exotic grasses inhibit establishment of other plant species. Buffelgrass and Kleberg bluestem inhibit seed germination of Illinois bundleflower (*Desmanthus illinoensis*) and partridge-pea (*Cassia fasciculata*), 2 forbs that produce seeds important as food for quail (Nurdin and Fulbright 1990). Planting extensive stands of these exotic grasses could be extremely detrimental to quail food plants, particularly if other native forb species are equally susceptible to germination inhibition.

Soil nutrient availability is reduced by stands of exotic plants. Soils under stands of crested wheatgrass (*Agropyron cristatum*) have lower available nitrogen, total nitrogen, and carbon than soils under stands of native prairie grasses that established abandoned agricultural fields (Christian and Wilson 1999). Similarly, pastures seeded to monocultures of crested wheatgrass or Russian wildrye (*Elymus junceus*) are lower in organic matter and nitrate than native mixed prairie (Dormaar et al. 1995). The reduction in soil nutrients caused by exotic grasses may inhibit efforts to replace exotics with native plants to improve habitat for quail and may lower overall ecosystem productivity.

Soil characteristics may influence susceptibility of an area to invasion by exotics. Many invasive exotic species colonize disturbed sites characterized by high levels of nitrogen. Exotic plant abundance in Australia is positively correlated with soil phosphorus, whereas native plant abundance is negatively correlated with decreased soil phosphorus (Morgan 1998). Perennial exotic grasses of high biomass depended on high soil nutrient levels for successful establishment in the Australian study.

Certain plant communities or vegetation types are more vulnerable to invasion of exotics than others (Larson et al. 2001). Riparian zones are particularly at risk (Stohlgren et al. 1998). Communities with higher functional group richness may be slightly more resistant to invasion by exotics (Symstad 2000).

Invasion and establishment of non-native plants is often facilitated or increased by soil disturbance (Parker et al. 1993, Morgan 1998). Mowing allows the invasion of exotic plant species in tallgrass prairie (Gibson et al. 1993). Different soil disturbances may not be equivalent in the degree to which exotic plants invade following the disturbance (Kotani 1997). Different types of disturbances have different effects on native plants. Certain disturbances were more favorable to exotics than to native plants, but none were effective in preventing occupancy by exotics. Roadside planting of exotics increases the invasion of exotics into adjacent grasslands (Tyser and Worley 1992).

Soil disturbance is widely used by wildlife managers to increase the abundance of early-successional herbaceous plants that produce seeds or herbage eaten by quail (Robel et al. 1996). Rather than improving habitat for quail, disking may increase the invasion of exotic plants. In southern Texas, canopy cover of buffelgrass was 7 times greater on soils disked 5 years earlier than on undisturbed soils (T. E. Fulbright, unpublished data). More frequent disking may intensify the invasion of exotic plants. Russian thistle (*Salsola kali*) was absent on undisturbed soils. One year after the final disking treatment, soils disked annually for 5 years supported a 40% canopy cover of Russian thistle compared to only 13% on soils disked only once.

The effects of livestock grazing on invasion by exotic plants are variable. Grazing has little effect on spread of exotic plants in Rocky Mountain grasslands (Stohlgren et al. 1999). Lehmann lovegrass invades semiarid grassland in the absence of cattle grazing, but higher grazing intensities increase relative abundance of the grass (McClaran and Anable 1992).

Although disturbance may exacerbate the spread of exotic plants, disturbance is not a prerequisite for invasion (Symstad 2000, Larson et al. 2001). Crawley (1987) suggested that all communities are susceptible to invasion if the introduced species has superior competitive or demographic traits. Five of 6 abundant exotic plant species in Theodore Roosevelt National Park have distributions unrelated to disturbance (Larson et al. 2001).

Exotic plant invasions clearly alter the ecological processes of the native plant communities that are invaded. Some alterations are subtle while others are more obvious. Perhaps the most striking negative effect that exotic grass invasions may impose on native plant communities is reduction of soil nutrients. Native forb and grass diversity and abundance declines as invaded soils become impoverished. The negative effects may cascade and eventually include reduced insect and bird biodiversity and abundance as reported by Bock et al. (1986) for an invaded southeastern Arizona

grassland. It would appear that exotic grass invasions result in simplified ecological communities.

QUAIL POPULATIONS AND EXOTIC GRASSES

Each of the 4 native quail species that inhabit the southwestern United States, have specific habitat requirements. Some of these habitat requirements are specific to each species, while other requirements appear to be universally shared among species. Forbs for example, are essential dietary items for masked bobwhites (Brown 1989, United States Fish & Wildlife Service 1995), scaled quail (Schemnitz 1961, Medina 1988), Gambel's quail (Brown 1989), northern bobwhites (Lehmann 1984:188, Guthery 1986:145), and to a lesser extent Montezuma quail (Leopold and McCabe 1957, Brown 1989). Similarly, habitats that support a diverse and abundant invertebrate community are important to all four quail species because insects are essential food items of young chicks, as well as adults for at least portions of the year (Schemnitz 1961, Lehmann 1984:192, Guthery 1986:147, Brown 1989). Additionally, herbaceous habitats that provide adequate nesting, escape, thermal and brooding cover are important to each quail species (Schemnitz 1961, Brown 1989, King 1998, Guthery et al. 2000), except Gambel's quail relative to their nesting requirements, because Gambel's quail nests are often nothing more than a depression in the shade of a shrub (Brown 1989). Therefore, exotic grass invasions could negatively impact southwestern quail populations if invasions limit one or more of the habitat attributes required by quail to fulfill their specific life history requirements. However, it is also possible that the presence of exotic grasses benefit quail populations by providing a habitat attribute that was limited or missing prior to exotic grass invasions.

Unfortunately, few studies have been conducted to determine how exotic grasses specifically impact quail populations, and the few studies that have been completed were done in the Southeast and Midwest and offer mixed results. For example, Burger et al. (1990), and Burger (1993) believed that Conservation Reserve Program (CRP) fields consisting of the exotic grass tall fescue (*Festuca arundinacea*) and red clover (*Trifolium pratense*) established in northern Missouri provided habitat conditions suitable for northern bobwhite production. However, Barnes et al. (1995), concluded that tall fescue fields in Kentucky provided poor bobwhite habitats. Washburn et al. (1999) advocated improving areas dominated by tall fescue in Kentucky by killing the plant and replacing it with native grasses, because native plants provided better habitat conditions for bobwhites. Clearly additional research is needed to quantify the specific impacts of exotic grass invasions on quail populations throughout the country, but particularly in the Southwest where almost none of this type of research has been conducted.

In the absence of relevant research results, we will discuss the potential impacts of exotic grass invasions

on southwestern quail populations based on what we know about important habitat requirements for each species. More importantly, we will relate some of the plant community alterations that result from exotic grass invasions identified in the previous section, to the availability and abundance of important quail habitat attributes in areas that have been invaded.

MASKED BOBWHITES

Masked bobwhites are the least studied of the 4 species of quail native to the Southwest. Therefore, their life history is not well documented. The few research projects completed, indicate that masked bobwhite life history is similar to that of bobwhites in south Texas (Simms 1989, King 1998, Guthery et al. 2000). Nevertheless, the habitat needs of masked bobwhites remained very obscure until recently. This dearth of information prompted biologists from the United States Fish & Wildlife Service (USFWS) to assume for years that Lehmann lovegrass on and around the Buenos Aires National Wildlife Refuge (BANWR) in the Altar Valley south of Tucson, and buffelgrass in northcentral Sonora, Mexico were detrimental to masked bobwhite recovery efforts (Kuvlesky et al. 2000). Based on meager, mostly anecdotal observations, it was assumed that diverse stands of native grasses provided better habitat than exotic grass stands. However, recent research indicated that masked bobwhites inhabiting BANWR were equally as likely to be found in stands of Lehmann lovegrass as in stands of native grass (King 1998). Though no scientific proof currently exists, exotic grass stands may provide essential cover to masked bobwhites during periods of drought. For example, Sonoran and USFWS biologists monitoring masked bobwhite populations on Rancho El Carrizo, Sonora, Mexico during a severe drought in the mid-1990s noted that most masked bobwhite observations occurred in buffelgrass, because cattle had consumed virtually all of the native grasses leaving buffelgrass as the only herbaceous cover available (Kuvlesky et al. 2000). During another drought in 1998, while masked bobwhites were being located for translocation to BANWR, every covey found was utilizing the cover provided by buffelgrass, again because it was the only herbaceous cover available (Kuvlesky et al. 2000).

However, during drought when masked bobwhites used pastures where buffelgrass was the dominant herbaceous feature, prairie acacia (*Acacia angustissima*) seeds, a favorite masked bobwhite food (United States Fish & Wildlife Service 1995), appeared to be abundant. When droughts ended and native grass and forb populations recovered, quail began utilizing areas dominated by native vegetation, though continued use of buffelgrass remained evident. Buffelgrass and Lehmann lovegrass may serve as important herbaceous cover for masked bobwhites, particularly when native herbaceous cover is limited. The superior structural and species diversity of native grass stands probably offer more food advantages, and possibly cover ad-

vantages, than stands of exotic grass. It is possible that masked bobwhites would have used, or even preferred native grass cover on Rancho El Carrizo during drought had it not been preferentially removed by cattle. Also, as mentioned previously in this paper, forb populations generally decline as exotic grass invade native plant communities, and this situation cannot be good for masked bobwhites because an important source of food is less available. Another important food, invertebrates, could also be negatively impacted by exotic grass invasions in the Southwest, though research conducted by Burger (1993) in a more mesic area of Missouri indicated that diverse and abundant invertebrate fauna inhabited tall fescue fields that included red clover. Nevertheless, in the arid southwest insect diversity and abundance is likely lower in exotic grass plantations (Bock et al. 1986) than native grass stands because legumes and forbs that attract insects are suppressed by exotic grass infestations (Medina 1988). Native plant communities likely provide better habitat conditions than exotic grass plantations because herbaceous species and structural diversity is probably superior, and these characteristics yield better cover and food conditions for quail. Masked bobwhites obviously use exotic grass, however it is probably useful only as cover. Unless food-producing plants like prairie acacia occur in exotic grass plantations, food supplies are probably limited forcing masked bobwhites to fulfill their nutritional requirements elsewhere. For example, King (1998) found that masked bobwhites displayed no preference for native grass stands over Lehmann lovegrass stands. She did note that masked bobwhite coveys found in Lehmann lovegrass were never far from extensive stands of native grasses suggesting that native grasses were important to masked bobwhites.

SCALED QUAIL

In addition to masked bobwhites, King (1998) also studied scaled and Gambel's quail on the BANWR, and much of this work was later summarized by Guthery et al. (2001). Like masked bobwhites, scaled and Gambel's quail did not prefer native grass. Instead, scaled quail preferred upland habitats with 10–15% woody cover, and on the BANWR, the dominant herbaceous species on these uplands was Lehmann lovegrass. Brown (1989) also noted that scaled quail in Arizona preferred level, semi-arid grasslands interspersed with short shrubs and cacti. He did not mention Lehmann lovegrass, stating only that grasslands favored by scaled quail consist of perennial bunchgrasses. Medina (1988) however, reported that scaled quail in Arizona were less abundant in stands of Lehmann lovegrass and more abundant in open areas with low perennial grass cover and high forb cover. Washes and other disturbed sites that were characterized by low perennial grass cover and high forb cover were frequented by scaled quail. His food habit data revealed that scaled quail consumed proportionally more forb seeds than any other plant item, and that bristle-

grass (*Setaria grisebachii*) seeds were the dominant grass component of diets. Insects were important foods during the summer, and on an annual basis ranked third behind forbs and grass seeds. Lehmann lovegrass appeared to be an unimportant food item. Schemnitz (1961) noted similar habitat preferences in the Oklahoma Panhandle. He reported that during his study in the mid-1950s, scaled quail thrived on the low-successional habitat conditions provided by the livestock and grain crop agricultural production typical on the shortgrass prairie at the time. Forbs and insects, which made up most of quail diets were abundant. When Schemnitz (1993) visited his former study site during the early 1990s he reported that scaled quail populations had declined and he attributed this decline to the prevalence of modern farming and CRP fields that consisted of dense stands of perennial grasses which provided scaled quail with some cover, but little food. Other studies have also indicated that scaled quail avoid areas of dense vegetation in favor of habitats with more diverse species composition and structure (Goodwin and Hungerford 1977, Campbell-Kissick 1985).

Perennial grasses, including Lehmann lovegrass, therefore may offer some cover value to scaled quail populations, but if Lehmann lovegrass offers little food and quail are supposed to avoid dense stands of Lehmann lovegrass, why do scaled quail appear to frequent uplands on the BANWR dominated by this exotic plant? Medina (1988) probably provided a clue when he stated that scaled quail preferred washes and other disturbed sites on his Arizona study area. The BANWR, and many other federal, state and private lands inhabited by scaled quail in Arizona, has numerous dirt roads, and dry washes located within its boundaries that represent frequently disturbed areas. Moreover, thousands of rodent excavations as well as hundreds of headcuts created by sheet and rill erosion provide numerous additional frequently disturbed sites where forbs are abundant. Scaled quail that inhabit extensive uplands dominated by Lehmann lovegrass may be able to exist on these areas because of numerous disturbed sites that provide a reliable source of seeds and greens. Invertebrates may also be more abundant on these sites than in Lehmann lovegrass stands. Scaled quail probably tolerate exotic grass plantations if a sufficient number of disturbed areas are present to support forb and insect populations. However, extensive exotic grass plantations that lack disturbed sites are unlikely to be used by scaled quail.

GAMBEL'S QUAIL

Unlike scaled quail, Gambel's quail require habitat with more woody cover (Guthery et al. 2001). Gambel's quail not only consume more mast than scaled quail or bobwhites, they also roost in bushy shrubs and small trees (Brown 1989). Overgrazing in the Southwest generally favors the development of shrublands (Burgess 1995) which benefits Gambel's quail over scaled quail and masked bobwhites because both spe-

cies are less tolerant of the conversion of grasslands to shrublands (Brown 1989). Gambel's quail are an arid-land species that have successfully adapted to the Sonoran Desert in Arizona, where perennial grasses are infrequent (Brown 1989). However, they are also the most abundant quail species on semi-arid grasslands that are at higher elevations within and around the Sonoran Desert. Gambel's quail are also extremely adaptable, a behavioral trait that permits them to successfully occupy large urban areas like Phoenix and Tucson. Since, numerous exotic shrub species are propagated in these urban habitats frequented by Gambel's quail it is likely that they have adapted to the presence of these plants and use them as roosting habitat and escape cover.

The adaptability of Gambel's quail permit them to occupy virtually every vegetation cover type on the Sonora savanna grasslands that make-up the BANWR, and they are the most abundant quail species in most cover types on the Refuge (Kuvlesky unpublished data). During annual winter quail surveys, BANWR Biologists observed more Gambel's quail on uplands dominated by Lehmann lovegrass than scaled quail. Gambel's quail were also the most abundant species on Rancho El Carrizo, Sonora, Mexico, and were as likely to be located in buffelgrass pastures as pastures dominated by native grasses. Large expanses of Lehmann lovegrass and buffelgrass likely impact Gambel's quail populations less than other quail species because sufficient shrub cover is present and bare disturbed areas have abundant forb populations, Gambel's quail seem able to maintain self-sustainable numbers where exotic grasses are the dominant grass species. It is possible that Lehmann lovegrass and buffelgrass enhance Gambel's quail habitat on semi-arid grasslands by providing an additional source of cover. Nevertheless, where exotic grasses suppress forbs and insect populations, Gambel's quail populations may be reduced.

Another exotic grass species however, may pose a genuine threat to Sonoran Desert ecosystems and the Gambel's quail populations that occupy areas that are being invaded. Red brome (*Bromus rubens*) probably first appeared in California from the Mediterranean region of Eurasia several decades ago where it became naturalized and then rapidly began invading semi-arid and arid ecosystems at an alarming pace (James 1995). Like cheatgrass (*Bromus tectorum*) in the Great Basin deserts and buffelgrass in Sonora, Mexico, red brome is a fire adapted species that modifies natural fire cycles in a manner that continually perpetuates invasion of additional acreage (D'Antonio and Vitousek 1992). The abundant fine fuel loads produced by red brome increase fire frequencies in invaded areas which results in the suppression of shrubs. Red brome invasion of the Sonoran Desert is a serious concern because shrubs and succulents are the dominant vegetation types of this desert. Native herbaceous vegetation consists almost entirely of desert annuals that are ephemeral in that these species must have winter precipitation to complete their life cycles. Consequently, because fine fuels are largely absent during summer thunderstorms,

lightening-caused fires are rare in the Sonoran Desert, and lack of fire facilitates the continued dominance of shrubs and succulents. However, saguaros (*Carnegiea gigantea*), mesquite (*Prosopis glandulosa*), and ironwood (*Olneya tesota*) populations gradually decline with the increased fire frequency that accompanies red brome invasions of the Sonoran Desert. It seems likely then, that Gambel's quail populations will decline in areas invaded by red brome in response to the gradual disappearance of the native Sonoran Desert shrubs which are critical to quail survival (Engel-Wilson unpublished data). If red brome invasion of the Sonoran Desert continues unabated, the future status of Gambel's quail may begin to resemble the current status of bobwhites in the Southeast.

MONTEZUMA QUAIL

Like the masked bobwhite, Montezuma quail have not been studied to any great extent by quail biologists. Therefore, nothing has been done to quantify the impacts of exotic grass invasions on this species. Montezuma quail typically occupy Mandrean oak (*Quercus* sp.) woodlands at elevations >1200 m though they use semi-arid grasslands slightly below this elevation during certain times of the year (Brown 1989). Like masked bobwhites, Montezuma quail require substantial herbaceous cover to survive. Brown (1982) described optimal habitat as consisting of 30% tree crown cover and 70% grass cover. Native warm season, perennial bunchgrasses represent preferred herbaceous cover. Brown (1989) does not mention exotic grass species as being important to Montezuma quail. Instead he states that bunchgrass species composition varies with locality and site though preferred herbaceous habitats consist of tall native species, such as sideoats grama (*Bouteloua curtipendula*), cane beardgrass, (*Bothriochloa barbinodis*), wolftail (*Lycurus setosus*), green sprangletop (*Leptochloa dubia*), and Texas bluestem (*Andropogon* spp.). Montezuma quail also use sites consisting of shorter species such as blue grama (*B. gracilis*), hairy grama (*B. hirsuta*), and three-awns (*Aristida* spp.), though these habitats are less desirable than those composed of taller grasses. Montezuma quail food habits do not include grasses other than the seeds of paspalums (Brown 1989). The bulbs of wood sorrels (*Oxalis* spp.) and bulbs and tubers of flat sedges (*Cyperus esculentus*, *C. rusbyi*) are the predominate foods consumed during October–June (Leopold and McCabe 1957, Bishop and Hungerford 1965). Acorns are important foods when they are available and insects, particularly beetles (Coleoptera), are important to both adults and chicks during the nesting and brood-rearing season of late summer and early fall (Brown 1989).

Given what is known about the life history and habitat requirements of Montezuma quail, exotic grass invasions apparently result in habitat loss. A diversity of tall bunchgrasses, abundant oxalis bulbs and sedge tubers, as well as abundant and diverse insect populations are required to maintain viable Montezuma

quail populations. Since exotic grass infestations reduce native grass and forb diversity, we speculate that Montezuma quail populations decline in response to exotic grass invasions.

NORTHERN BOBWHITE

A substantial amount of research has been conducted on northern bobwhites throughout the species range in Texas and Oklahoma because bobwhites are popular among hunters and private landowners (Guthery 1986:251, Brown 1999). Quail biologists have ample information available to them to effectively implement brush management, grazing management, and hunting management programs that benefit northern bobwhite populations in the Southwest. It is odd, that few researchers have examined the impacts of exotic grass invasions on bobwhites when hundreds of thousands of hectares of exotic grass exist in Texas alone. Perhaps bobwhite researchers have avoided broaching the subject with private landowners, because many cattlemen believe that exotic grasses, especially buffelgrass, are good livestock forage. However, it would be in the best interests of many ranchers who derive income from quail hunting to know if exotic grass invasions are detrimental to bobwhite populations inhabiting their properties. Despite this logic, exotic grass/quail research has been neglected for northern bobwhites in the Southwest.

A few notable quail biologists with years of experience working with quail in south Texas, developed opinions regarding the impacts of exotic grasses on quail populations. For instance, Lehmann (1984:287) advocated restoring rangelands to high quality perennial bunchgrasses and legumes in order to increase bobwhite densities in south Texas. He furthermore stated that management activities that promote large expanses of buffelgrass, Kleberg bluestem or any other nonfood-bearing exotic species should be avoided if increasing quail numbers is a management goal. Guthery's (Oklahoma State University, Stillwater, personal communication) extensive research on northern bobwhites in south Texas lead him to believe that it was unreasonable to assume that exotic grass invasions were universally negative for bobwhite populations inhabiting southwestern rangelands. For example, he observed that King Ranch bluestem infestations and invasions provided poor quail habitat conditions throughout south Texas. Conversely, he noted that in one instance, quail surveys on ranch infested with buffelgrass produce estimates of 5 birds/ha (Guthery and Koerth 1992) which is a high density for south Texas. Precipitation was average to above average during the beginning and middle of the study, which suggests that native foods were probably adequate. Moreover, quail feeders and waterers were established on the study site at a density of 1 feeder/9 ha and 1 waterer/8 ha. Thus, bobwhites had ample food and water available to them otherwise a density of 5 birds/ha could not have been produced or sustained. Habitat quality on the study site was considered high, indicating that forbs were avail-

able to quail and thus were probably not a limiting factor. Clearly buffelgrass infestations on this ranch did not completely suppress forb populations. Nevertheless, given what is known about the impacts of exotic grass invasions on forb abundance, it is possible that forb numbers were considerably higher on the ranch prior to buffelgrass invasion. Pre-buffelgrass forb abundance may seem irrelevant from a quail management perspective because post-buffelgrass forb abundance was sufficient to support a density of 5 birds/ha. However, during drought, forb abundance in buffelgrass pastures may be much lower than in a comparable pasture composed of native grasses, thereby reducing the quality of buffelgrass habitat to bobwhites.

Guthery's research in south Texas indicated to him that one should not generalize about the impacts of exotic grass invasions on bobwhite populations (personal communication). Though Lehmann (1984:287) believed that exotic grass represented poor quail habitat, this belief was based largely on several decades of observation, which, though valuable, is not an alternative to good science. Similarly, Guthery and Koerth (1992) did not design their research to quantify the impacts of buffelgrass invasions on bobwhite populations. Their research was simply conducted on a ranch over a period of time when quail were abundant on their buffelgrass study sites. They never suggested that buffelgrass provided either good or bad habitat conditions for bobwhites. Instead we speculated that bobwhite populations were not significantly impacted by buffelgrass during their study. Unfortunately, speculation like anecdotal observation, does not prove or disprove anything. The truth is, like masked bobwhites, scaled quail, Gambel's quail, and Montezuma quail, we really do not know what impacts, if any, exotic grass invasions have on northern bobwhite populations.

RESEARCH AND MANAGEMENT NEEDS

The recent work of Burger et al. (1990), Burger (1993), Barnes et al. (1995), and Washburn et al. (1999, 2000) in the Midwest and Southeast represents almost all of the published research that addresses the impacts of exotic grasses on quail. Significantly more research needs to be conducted in a variety of ecoregions in North America to assess the impacts of exotic grass invasions on quail populations. The research of Bock et al. (1986) indicated that exotic grass invasions resulted in lower avian diversity in southeastern Arizona, and Schemnitz (1993) believed that exotic grass species planted to CRP fields in the Oklahoma Panhandle have negatively impacted scaled quail habitat conditions. Additionally, numerous anecdotal observations by other quail biologists working throughout the southwest suggests that exotic grass invasions may prove harmful to quail populations. Nonetheless, little scientific evidence presently exists implicating exotic

grass invasions as a legitimate threat to quail populations of the southwest.

Clearly, a logical beginning is to determine if a problem exists! Coarse-scale, retrospective analyses of trends in quail abundance could be correlated to trends in exotic grass invasions across regional landscapes to determine if scaled quail population declines in southeastern Arizona for example, are related to increasing exotic grass dominance of grassland landscapes. Similar retrospective studies could be done in south Texas for bobwhites and buffelgrass, in the Sonoran Desert for Gambel's quail and red brome, and in northcentral Sonora, Mexico and the BANWR of Arizona for masked bobwhites and buffelgrass and Lehmann lovegrass, respectively. In addition to retrospective studies, Geographic Information Systems could be used in conjunction with landscape-scale quail and vegetation data collected today to determine if quail abundance is impacted by landscapes dominated by exotic grasses. One would simply need reasonably accurate Global Positioning Systems, reliable four-wheel drive vehicles, access to a regional landscape and sufficient help to conduct quail surveys and regional assessment of the impacts of exotic grass on quail abundance could be accomplished.

If it can be established that quail numbers are lower on landscapes dominated by exotic grasses compared to quail numbers on landscapes dominated by native grasses, then research designed to determine the specific mechanisms responsible for lower quail numbers can be initiated. Incorporated in such a research project would be studies that illuminate the life history of the exotic grasses of interest so that potential vulnerabilities of the exotic plant could be identified, and then possibly exploited in an effort to reduce the negative impacts of the exotic grass on quail populations. For example, Biedenbender et al. (1995) knew that Lehmann lovegrass seed germination is enhanced by red light and fluctuating diurnal temperatures so they exploited these aspects of Lehmann lovegrass life history in an effort to suppress seedling germination. They succeeded in suppressing seedling expression in favor of native grass seedlings in southeastern Arizona by altering light, temperature and moisture relations in seedbed environments via a combination of spring glyphosate and June mowing treatments. Biedenbender et al. (1995) did not discuss how quail might benefit from the results of their work, however, suppression of Lehmann lovegrass in favor of native vegetation would benefit masked bobwhite and scaled quail populations if the observations of King (1998), Guthery et al. (2000), and Schemnitz (1963) are correct.

In addition to the work of Biedenbender et al. (1995), other researchers have demonstrated a direct relationship between suppressing exotic grass populations and improving quail habitat. Barnes et al. (1995) determined that tall fescue provided poor habitat conditions for quail, then Washburn et al. (1999, 2000) determined that a combination of seasonal herbicide application and prescribed burning significantly reduced tall fescue density on treated fields in favor of native grasses that enhanced bobwhite habitat condi-

tions. The results of these research projects are encouraging, because they indicate that tall fescue and Lehmann lovegrass populations can be reduced in Kentucky and Arizona, respectively.

There are however complications associated with exotic grass suppression that need to be considered on a species specific and site-by-site basis. For instance, methodology developed to slow or stop Lehmann lovegrass invasions in Arizona, may not succeed in Texas where climatic and edaphic factors are markedly different. Similarly, techniques that increase tall fescue mortality may have no impact on buffelgrass or red brome. Another problem associated with attempting to improve quail habitat conditions by reducing exotic grass populations concerns replacing the exotic grass with vegetation that is favored by quail. Presumably grasses and forbs native to the treated site would be the preferred post-treatment cover crop, however often native seedbanks have diminished or no longer exist on treated sites, because of sheet and rill erosion. Consequently, if a native cover crop is desired, seed must be purchased from commercial sources, and commercial sources of native herbaceous species endemic to specific locales are extremely limited in the Southwest and often impossible to acquire. Most often available native grass seed stocks are cultivated great distances from treatment sites where native grass seeding is desired, and attempts to establish native grass stands from commercially produced seeds sometimes yields poor results (Roundy and Biedenbender 1995).

Despite these challenges, successfully rehabilitating exotic grass infestations to improve quail habitat in the Southwest could be achieved if it is deemed a problem, and quail conservation is a priority among private and public land stewards. Clearly, additional research devoted to studying specific exotic grass species in specific locales will be required. However, before these research projects are initiated, important realities associated with exotic grasses in the Southwest need to be understood by everyone advocating exotic grass suppression. First, certain exotic grass species are perceived as important livestock forage by many livestock producers. As mentioned earlier in this paper, hundreds of thousands of hectares of a variety of exotic grass species have been established in the Southwest over the past 50 years by ranchers, as well as federal and state agencies to provide reliable forage for cattle. Ranchers in south Texas and northern Mexico in particular, continue to seed thousands of hectares of buffelgrass annually. Livestock producers are unlikely to advocate exotic suppression. So exotic suppression will have to be implemented on areas where exotic grass is viewed as a pest. Federal land managers of National Wildlife Refuges and National Parks are required to implement management activities that restore native flora and fauna, so Federal Refuge and Parks represent areas where exotic grass suppression research would likely be welcome. Exotic grass suppression would also be welcome on properties owned by private conservation organizations, such as the Nature Conservancy and the National Audubon Society, because these organizations are very interested in na-

tive flora and fauna conservation and restoration. Also, many ranchers actively promote exotic grass establishment, however, there are some private landowners who would prefer to manage for native vegetation for commercial and aesthetic reasons. These individuals may believe that native vegetation provides better habitat for bobwhites, and because quail are a valuable commodity in Texas, for example, some ranchers may be interested in initiating exotic grass suppression if they know that quail will benefit. Therefore, it is important to focus research efforts on lands where exotic species are regarded as pests and where suppression is desired.

The other important reality regarding exotic grass suppression is to understand very clearly that eradicating established exotics that are resilient aggressive invaders is impossible. Eradicating many naturalized exotic species, and perhaps even controlling them, are unrealistic expectations. Once established, non-native plants are extremely difficult to remove, since they are often subject to less pressure from competition or predation than native species (Palmer et al. 1997). Removal of exotic grasses by hand resulted in an increase in native shrubs in Hawaii (D'Antonio et al. 1998). Hand removal is impractical over large areas, and few economically feasible methods of biologically, chemically, or mechanically removing exotics are available. Rice blast (*Pyricularia grisea*) is pathogenic to buffelgrass. However, the fungus may also affect agricultural crops, thus its use as a biological control agent may not be advisable (Tix 2000).

Nevertheless, Heady (1999) believed that it may be possible to reduce populations of some exotic plant species, but he also believed it highly unlikely that elimination could be achieved once exotic vegetation becomes naturalized and firmly established. He noted that on a worldwide basis, efforts to eradicate alien invaders have generally failed. Furthermore Heady (1999) recognized that weed management, where the objective is partial or reasonable economic control, requires carefully designed research programs more than the selection and application of pesticides. Adopting a management philosophy is probably the most realistic approach to effectively deal with exotic grass infestations and invasions. Many private landowners in south Texas have implemented an integrated natural resource management program on their properties which integrates livestock, water, brush, and wildlife management in a manner that maximizes the economic potential of the natural resources on their properties. Because bobwhites are important commodities to many of these landowners they often manage livestock and brush in a manner that enhances quail production. If these landowners learn that exotic grass invasions could pose a threat to quail populations, they may be very responsive to cooperating in research projects designed to determine if, and how exotic grasses negatively impact quail populations. Similarly, these landowners may also be very receptive to incorporating exotic grass management into their integrated natural resource management programs, especially if exotic grass management benefits quail populations. Designating a series of pastures as exotic grass management

units and then focusing suppression activities on a different management unit each year would be an organized and economical way of managing exotic grass invasions on a ranch. Monitoring quail responses to exotic grass management activities could also be accomplished quite easily by establishing whistle counts surveys throughout management units, and then conducting quail surveys on an annual basis.

CONCLUSIONS

Thousands of exotic species have been introduced to the United States during the past century and numerous species that have successfully naturalized portions of North America are threatening the native biodiversity of the ecosystems that they currently occupy. Invasions of exotic plants modify microclimatic and edaphic features of native vegetative communities in a manner that creates progressively better conditions for the exotic plant invading the native system, thereby perpetuating invasion. An important consequence of exotic grass invasions appears to be the simplification of native biodiversity of the ecosystem being invaded. Exotic grass invasions are currently occurring on thousands of hectares of rangeland in the southwestern United States and little research has been conducted to determine how these invasions are impacting wildlife populations inhabiting these rangeland ecosystems. The meager work that has been done indicates that exotic grass invasions have a negative impact on the plant and animal communities that are being invaded. Bird communities in particular, may be impoverished as a result of exotic grass invasions because these invasions typically reduce herbaceous structural diversity, which not only reduces niche diversity, but also probably reduces forb and insect diversity.

Like northern bobwhite populations throughout most of their historic distribution, populations of most of the 5 native southwestern quail species are also declining in at least portions of their range. Scaled quail and Montezuma quail populations continue to decline throughout Texas, New Mexico, and Arizona. Masked bobwhites remain endangered in Arizona despite annual supplementation of captive-reared chicks to an introduced population. What is even more disturbing is that Gambel's quail and northern bobwhite populations that have been at least stable for decades in Arizona and south Texas, respectively, have recently exhibited indications that population declines are underway. These declines have largely been attributed to habitat loss due to overgrazing, increased agricultural crop production, and urban development. However, quail populations could also be losing useable habitat space to exotic grass invasions. Few studies have been conducted addressing the exotic grass/quail issue, and most of those that have been completed were conducted in the midwest or southeast and yielded mixed results. Nevertheless, recent grassland community studies indicate that essential quail habitat features could be negatively impacted by exotic grass invasions. Concern that exotic grass invasions could neg-

atively impact quail populations is therefore justified, until scientific evidence proves otherwise. Clearly a need exists to experimentally quantify the impacts of exotic grass invasions on quail populations in the southwest. Until research projects specifically designed to evaluate the impacts of exotic grass on quail populations are implemented, we will remain ignorant regarding the exotic grass invasion/quail issue.

ACKNOWLEDGMENTS

This is publication no. 02-102 of the Caesar Kleberg Wildlife Research Institute.

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